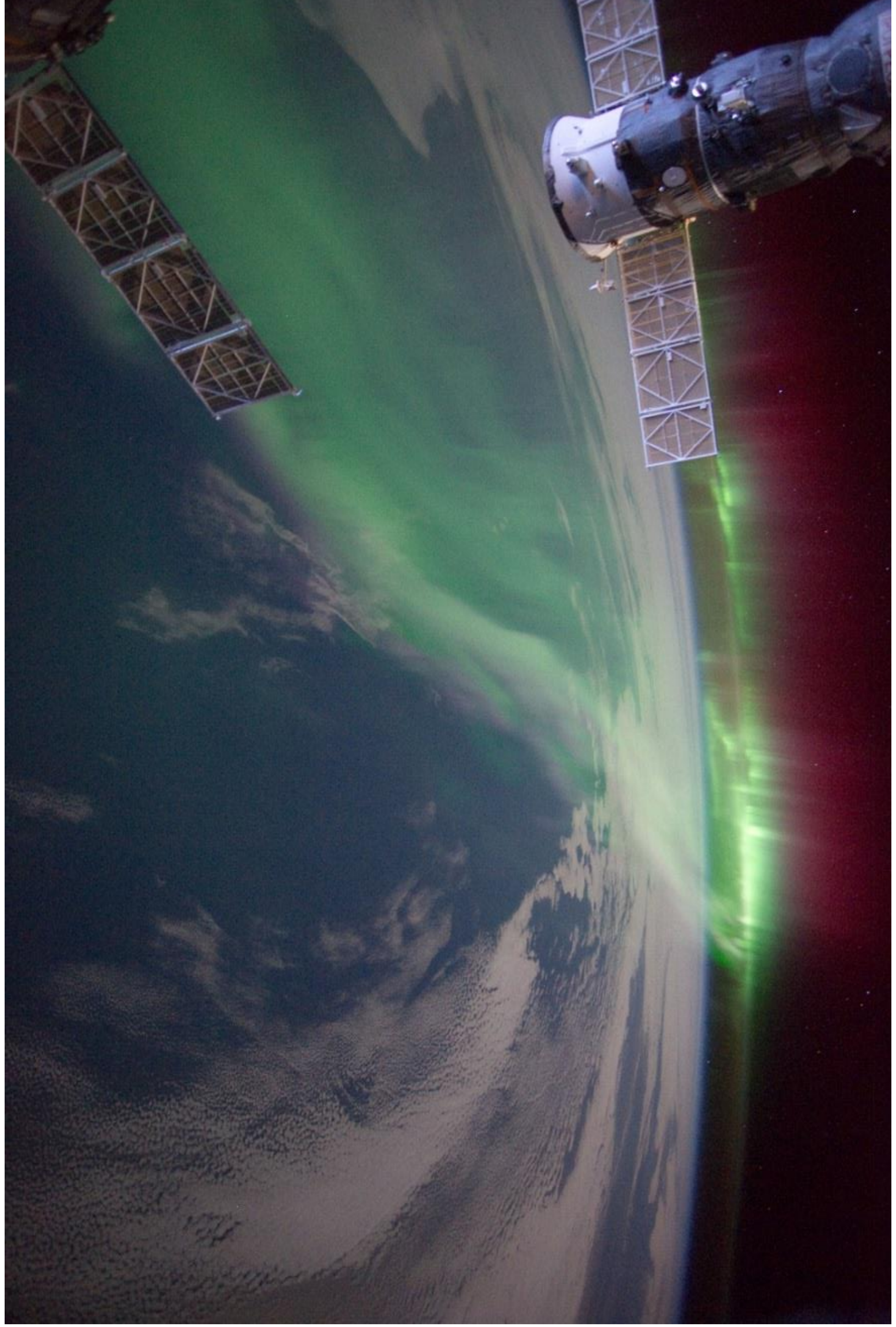

Update on FPMU Measurements of ISS Charging

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Introduction

- The Floating Potential Measurement Unit (FPMU) has provided in-situ measurements of ISS floating potential and plasma environments since August 2006

- FPMU measurements of ISS charging in previous SCTC presentations:
  - Coffey et al., *Validation of ISS FPMU Electron Densities and Temperatures*, 10th SCTC, 2007
  - Wright et al., *Initial Results from the FPMU aboard the ISS*, 10th SCTC, 2007
  - Minow et al., *Summary of 2006 to 2010 FPMU Measurements of ISS Frame Potentials*, 11th SCTC, 2010
  - Willis et al., *Correlation of ISS Electric Potential Variations with Mission Operations*, 13th SCTC, 2014
  - Minow et al., *Evidence for Arcing on the ISS Solar Arrays*, 15th SCTC, 2018

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- Our presentation today provides an update on observations of ISS charging based on FPMU measurements

Outline:
- FPMU
- Examples of ISS charging behavior
- FPMU replacement
- Access to FPMU data

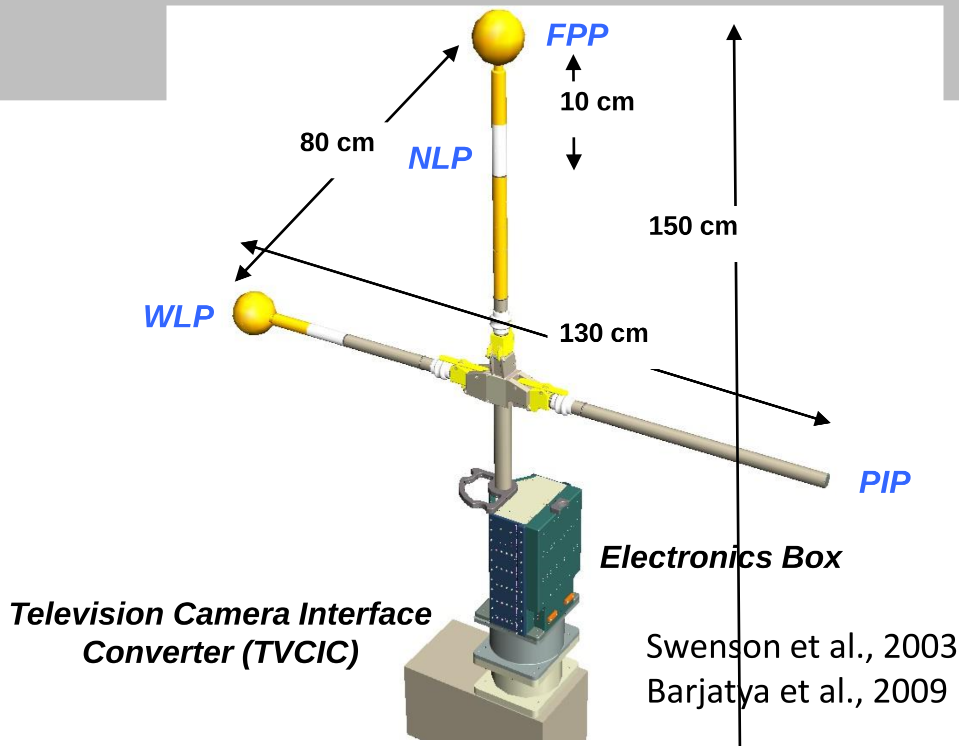
Floating Potential Measurement Unit (FPMU)

- FPMU is a suite of four plasma instruments originally deployed on the ISS in August of 2006, new instrument deployed September 2021
  - Narrow Langmuir Probe (NLP) 1 Hz Ne, Te, Ni, Vf, Vp
  - Wide Langmuir Probe (WLP) 1 Hz Ne, Te, Ni, Vf, Vp
  - Floating Potential Probe (FPP) 128 Hz Vf
  - Plasma Impedance Probe (PIP) 1 Hz Ne

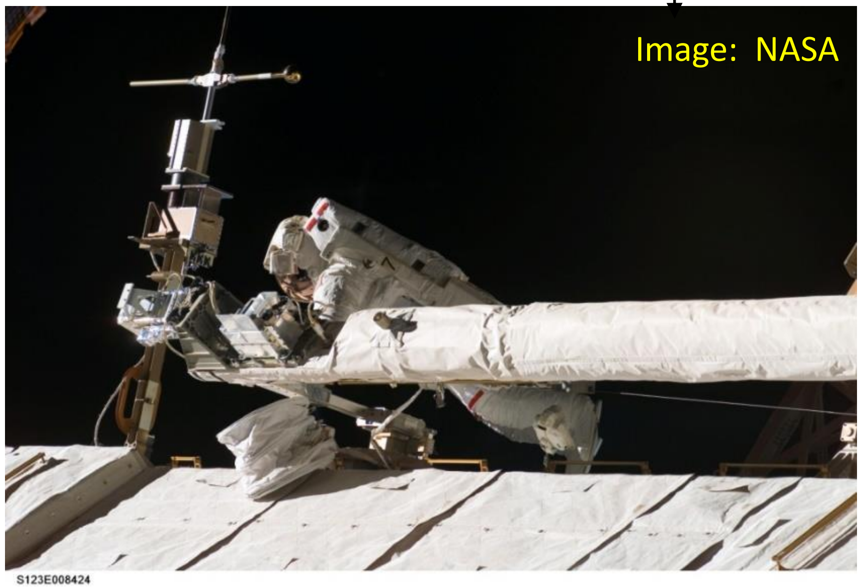
- Primary use is ISS engineering:
  - Characterize US 160 V solar array interactions with plasma environment
  - Evaluate EVA plasma hazard environments and vehicle charging
  - Validate the Plasma Interaction Model used to compute ISS frame potentials
  - Anomaly investigations

- Secondary use is ionospheric science applications:
  - Collaborations with ISS science payloads, other science missions, and ground-based ionosphere observations
  - Support studies of the topside ionosphere near electron density peak
  - Data provided to science community through Goddard Space Flight Center’s (GSFC’s) Space Physics Data Facility (SPDF)
  - Investigation auroral charging and ISS space weather interactions
  - Characterize geophysical events and spacecraft plasma interactions

- FPMU is operated on a campaign basis due to downlink and other constraints



Swenson et al., 2003; Barjatya et al., 2009



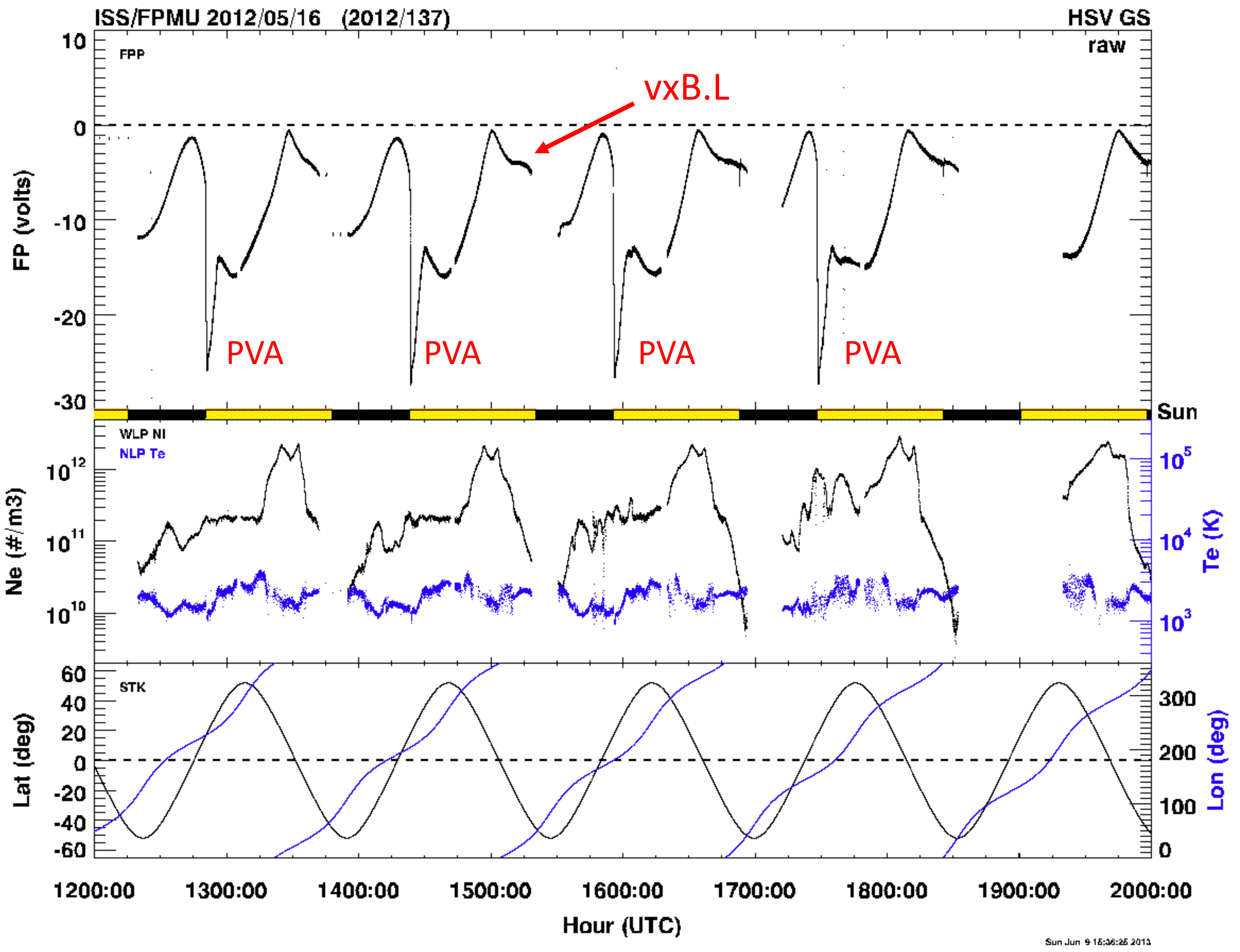
ISS Potential Variations

- ISS potential variations are due to
  - Current collection by US 160 V photovoltaic arrays (PVA)
  - Inductive (vxB).L across structure
  - Auroral charging
  - Visiting vehicles with high voltage PVAs
  - Payloads with current sources

- ISS structure is generally negative with respect to plasma since PVAs are grounded to structure on the negative end of the arrays

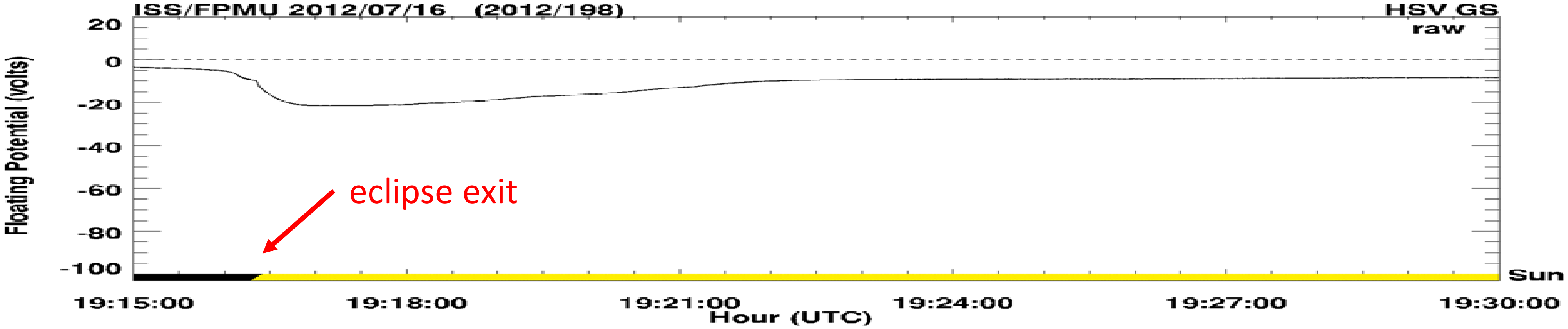
- Charging peaks following eclipse exit when arrays are biased, current collecting surfaces are in ram, and batteries are charging

- Charging decreases over daylight segment of orbit as strings are shunted when power needs decrease and arrays tracking the Sun rotate into wake

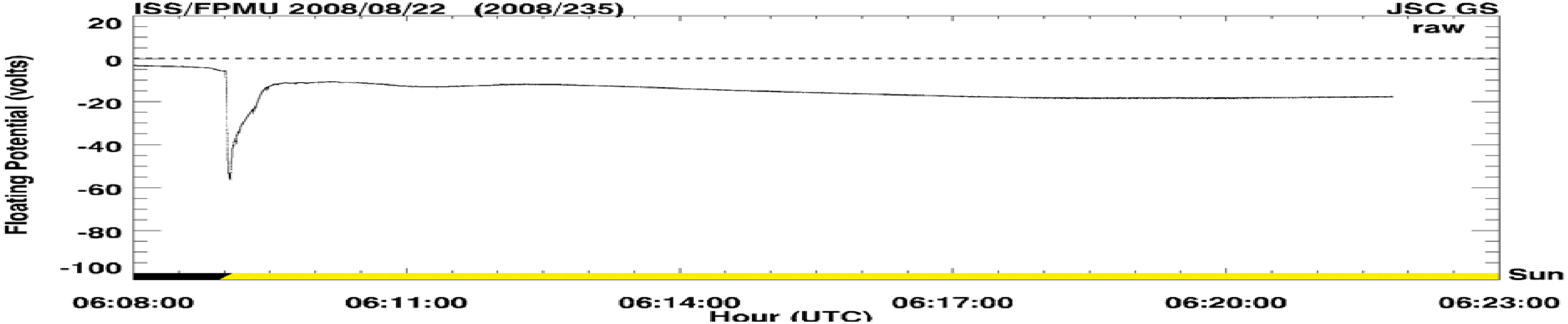


PVA Negative Charging

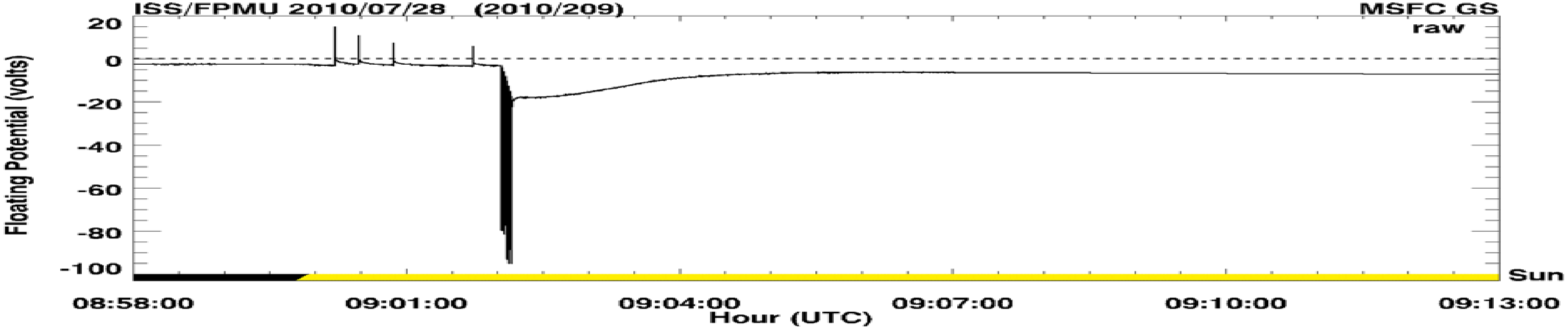
Normal



Rapid Charging Event (RCE)



Sunlight Unshunt



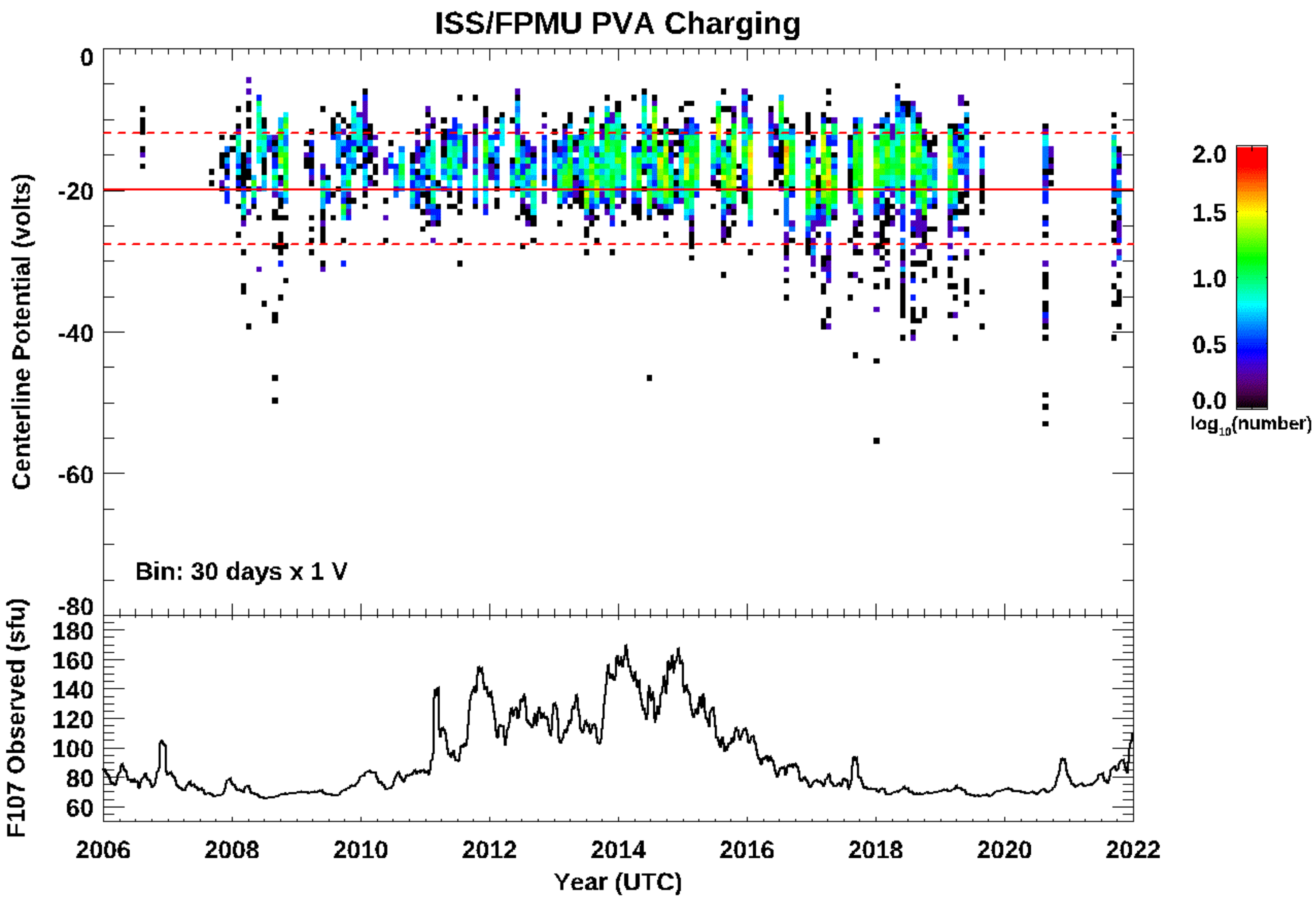
PVA Charging Statistics and Solar Cycle

- PVA normal negative charging typically peaks in the range of -10 V to -30 V:

5%	-12.0 V
50%	-19.9 V
95%	-27.6 V

- Largest PVA RCE negative charging in the -35 V to -70 V range occurs at eclipse exits with low plasma densities

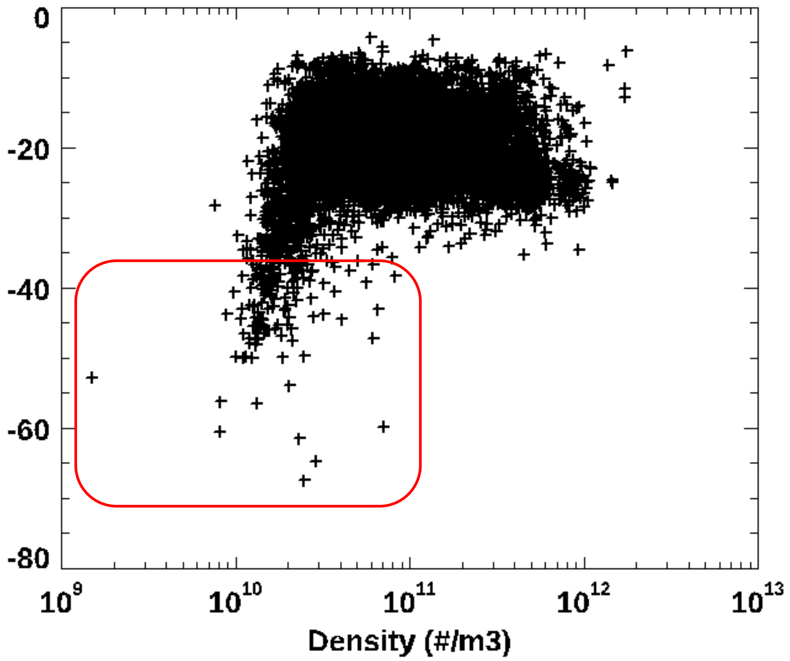
- RCEs correlate with solar cycle (because the low plasma density events are a function of solar activity)

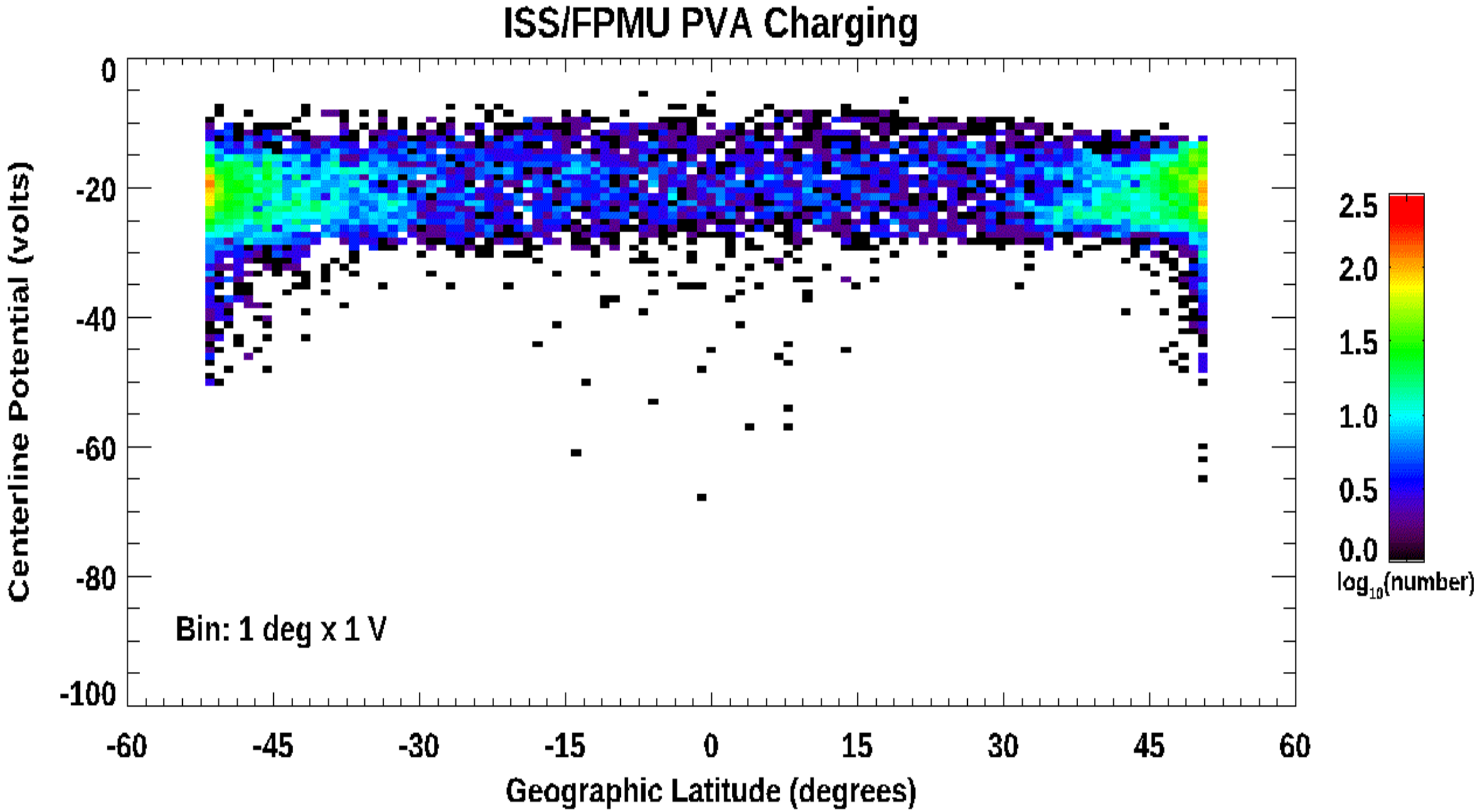


PVA Charging vs Latitude and Density

- RCE's occurrence peaks near the equator and at high latitudes
  - Equatorial dawn density depletions
  - High latitude ion troughs

- Large number of charging peaks at highest latitude is a sampling bias due to the 51.6° inclination orbit





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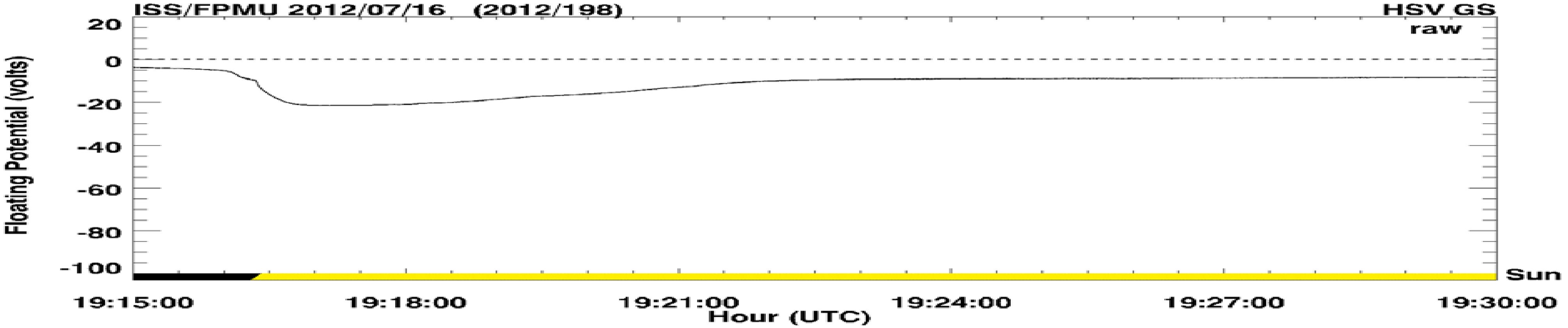

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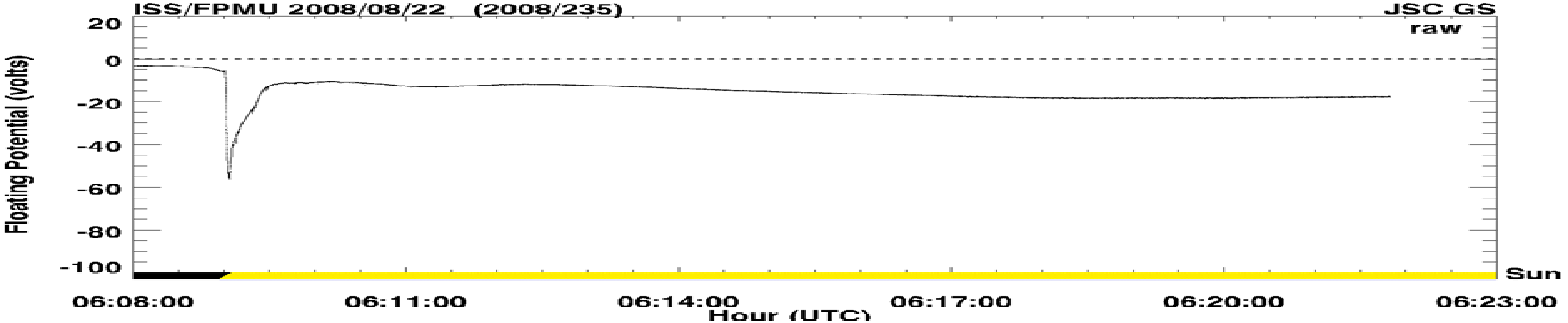
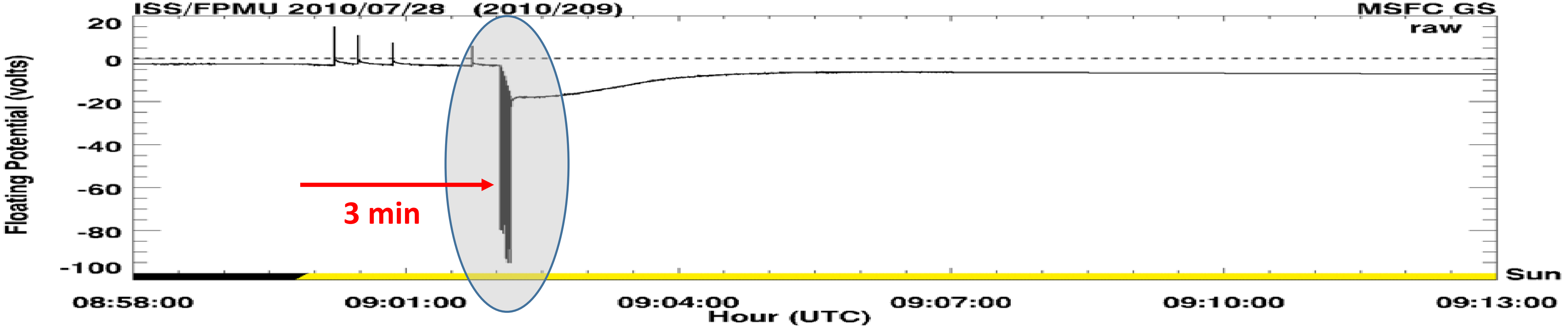


Sunlight Unshunt

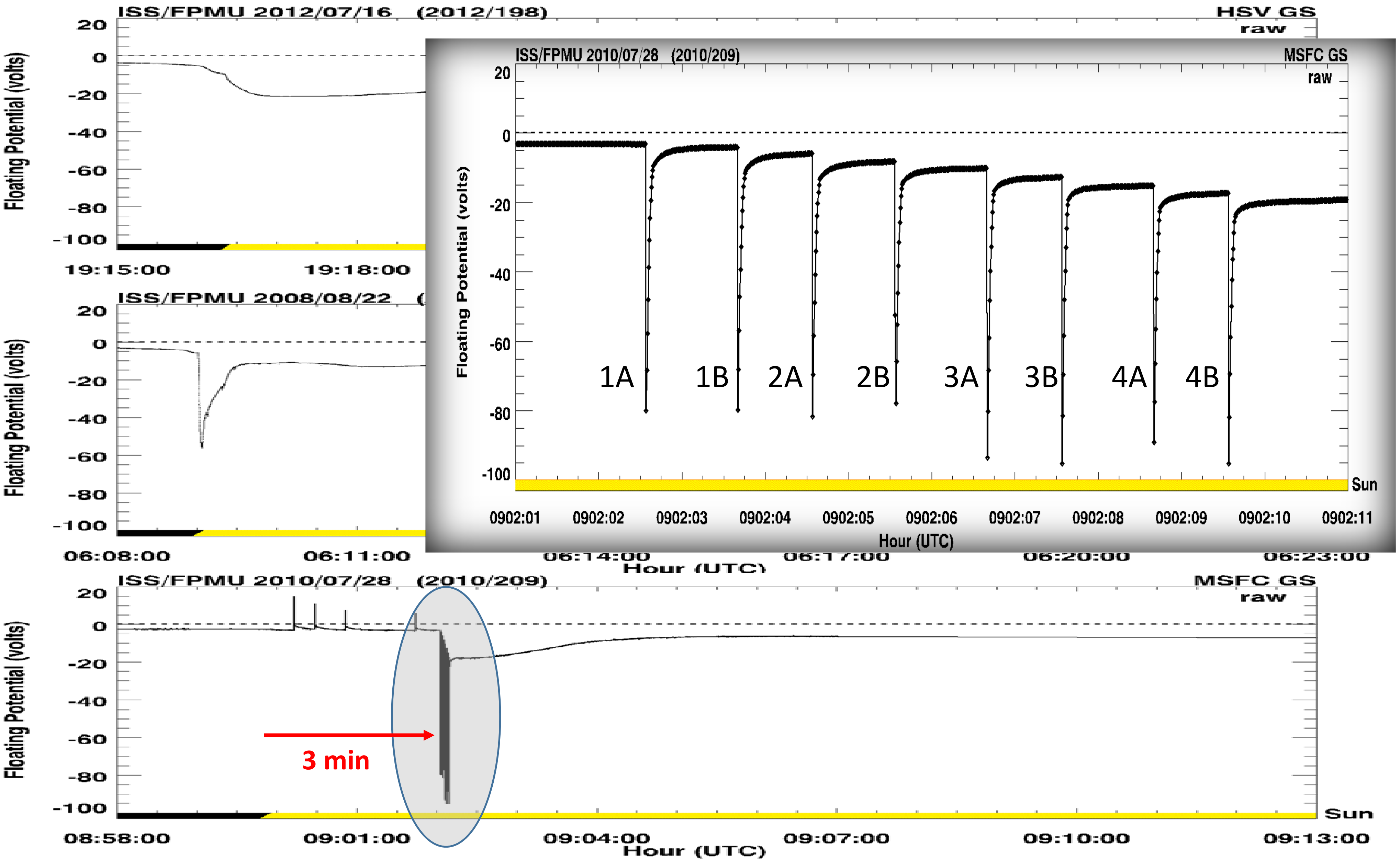


PVA Negative Charging – Sunlight Unshunt Experiment 2010

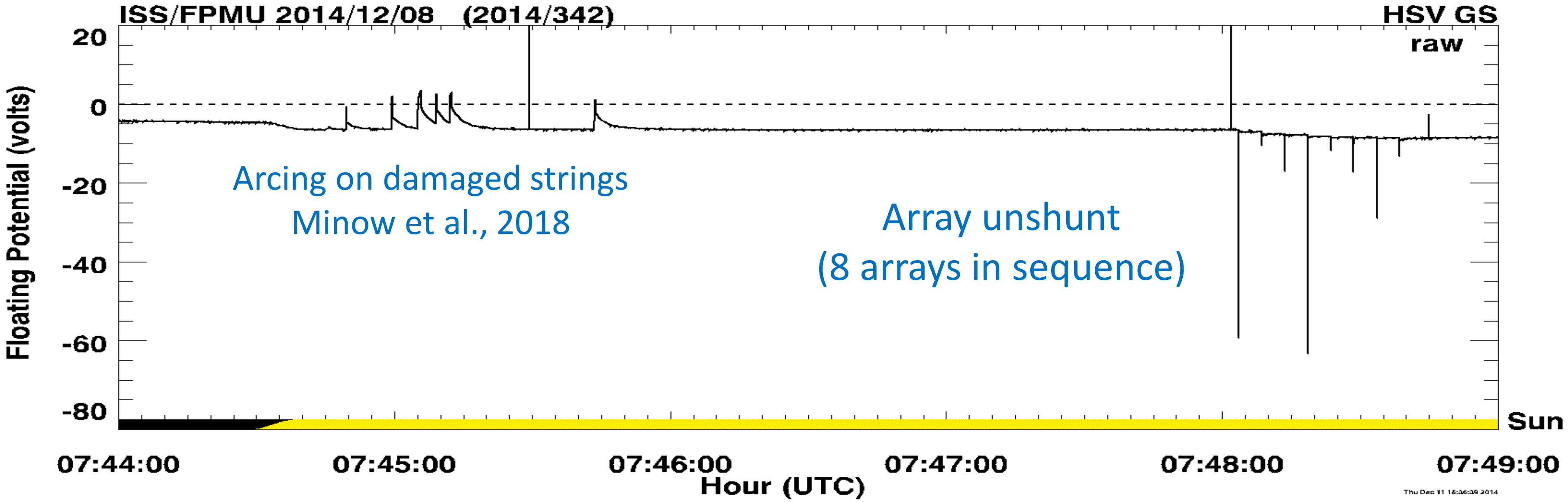
Normal

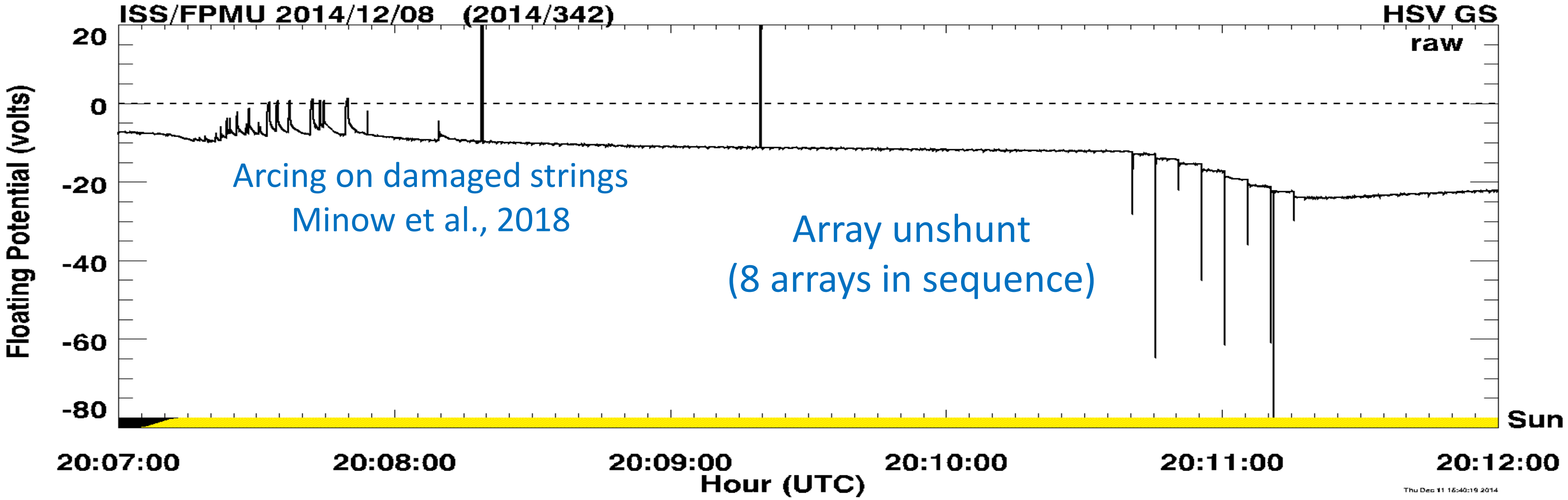
Rapid Charging Event (RCE)

Sunlight Unshunt



PVA Negative Charging – Sunlight Unshunt Experiment 2014





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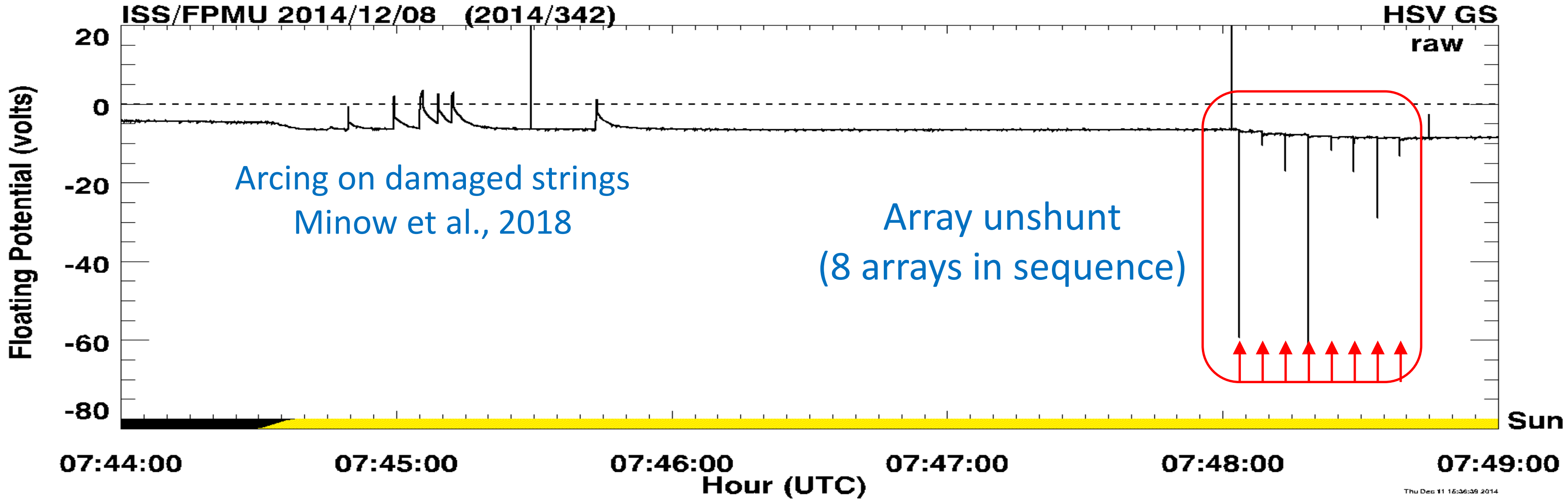
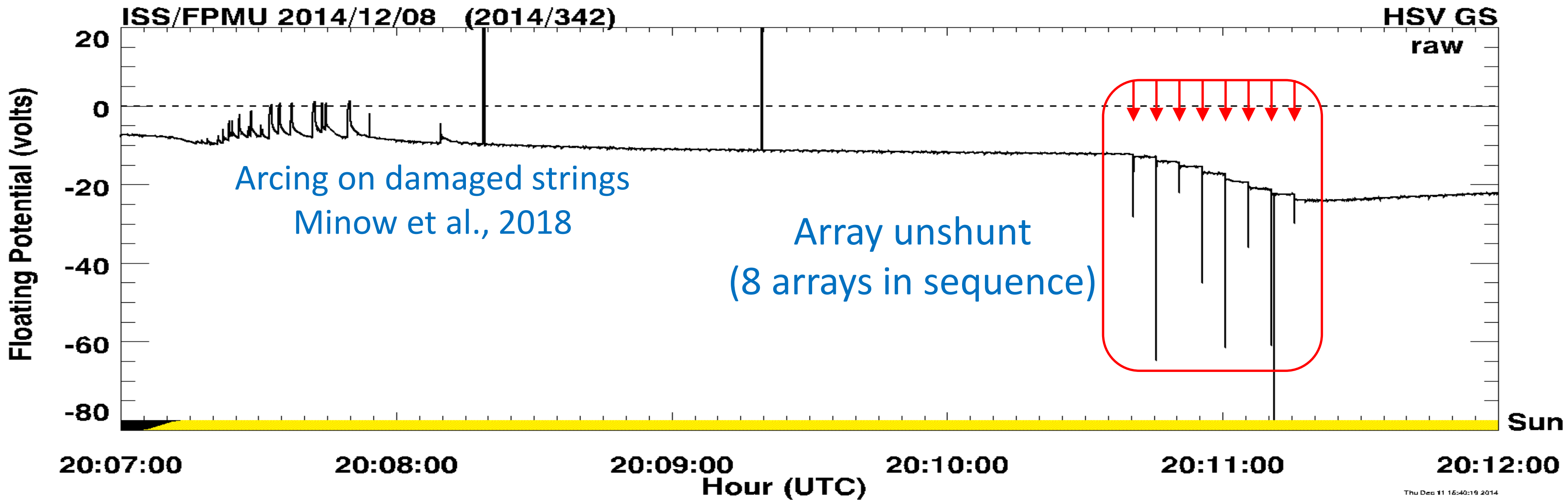
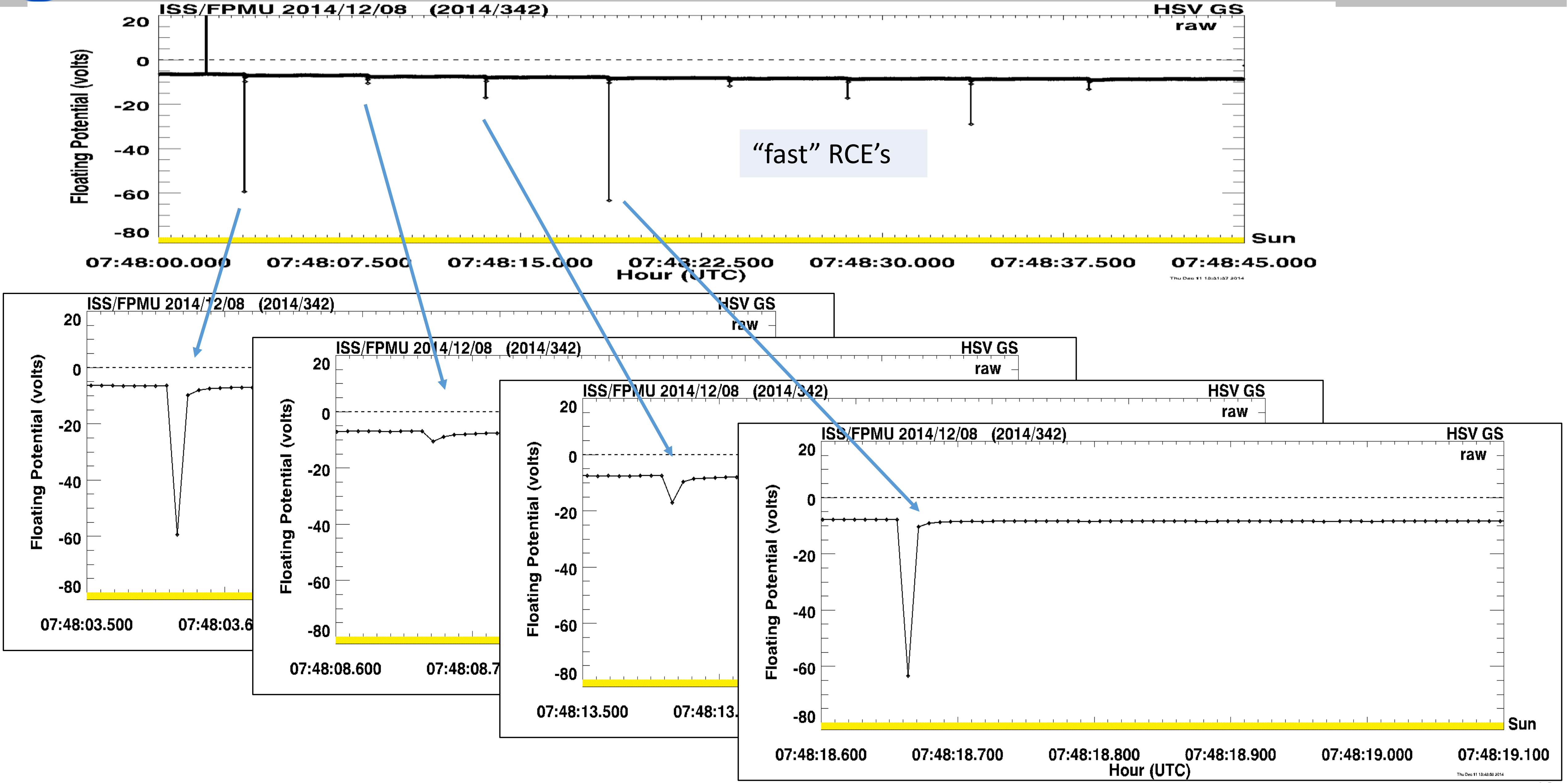




“Fast” RCE Details



Simulation of FPP 128 Hz Sampling

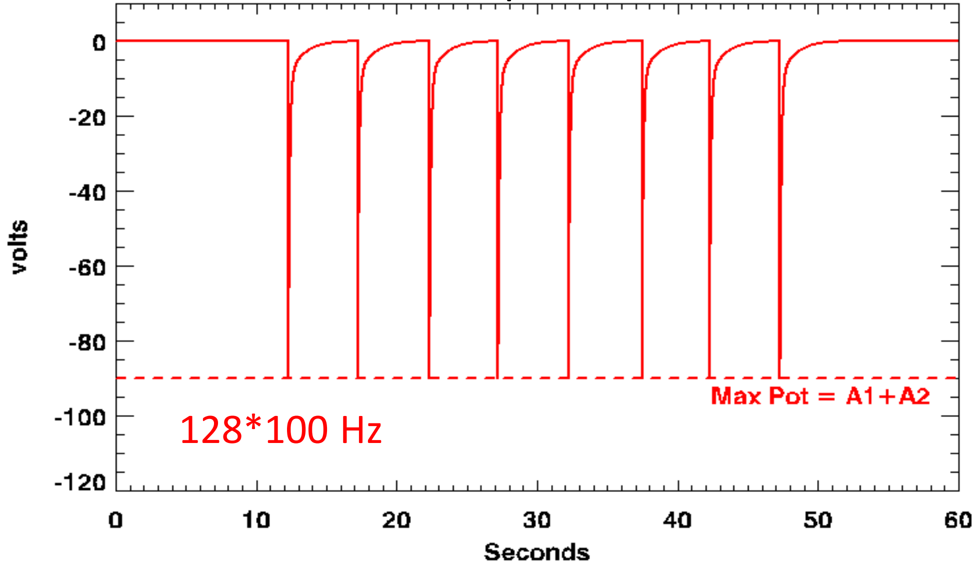
- Maximum value of RCE potential measured by FPP depends on how the 128 Hz sampling rate compares to time constants for RCE charging and discharging

- FPMU Sampling Model
  - Assume charging to maximum potential in 1/(100*128) sec = 0.78 µsec sample period
  - RCEs decay with time constants τ_1 and τ_2 for each of the k=1, 2,…, 8 charging peaks is given by:

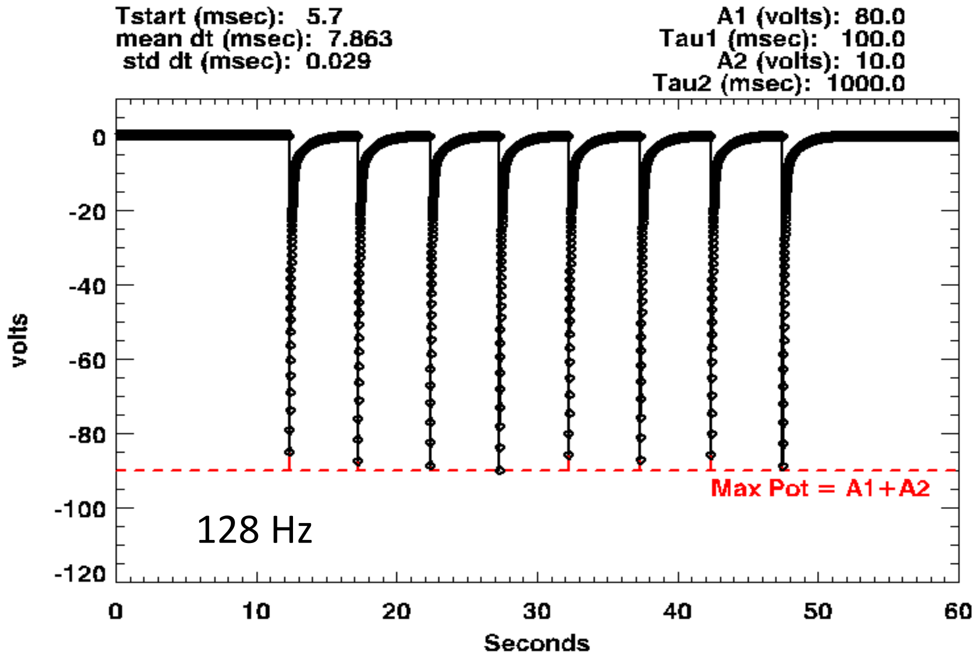
$$\varphi_k = A_1 e^{-(t-t_k)/\tau_1} + A_1 e^{-(t-t_k)/\tau_2} \quad \text{for } t \geq t_k$$
$$\varphi_k = 0 \quad \text{for } t < t_k$$

  - Simulate time series of RCE's generated at 128*100 Hz but sampled at 128 Hz
  - Unshunt commands at 10,15,20,…,45 sec
  - Random PVCE response latency with mean of ~2.34±0.08 sec
  - Random FPP start time in $0 \leq t_{start} \leq 1/128$ sec interval

Simulated ISS frame potential

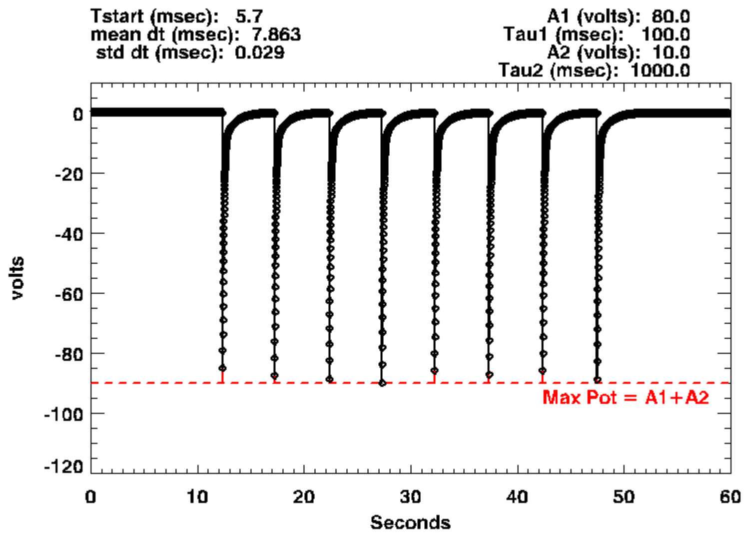


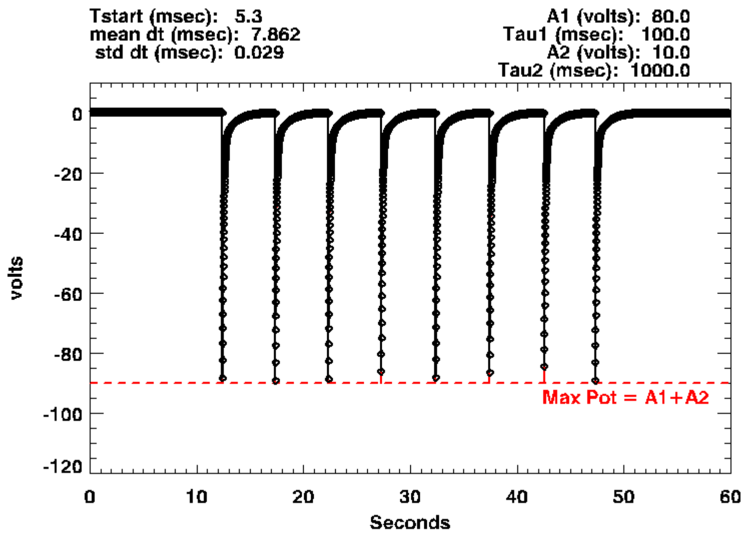
Simulated FPP sampling

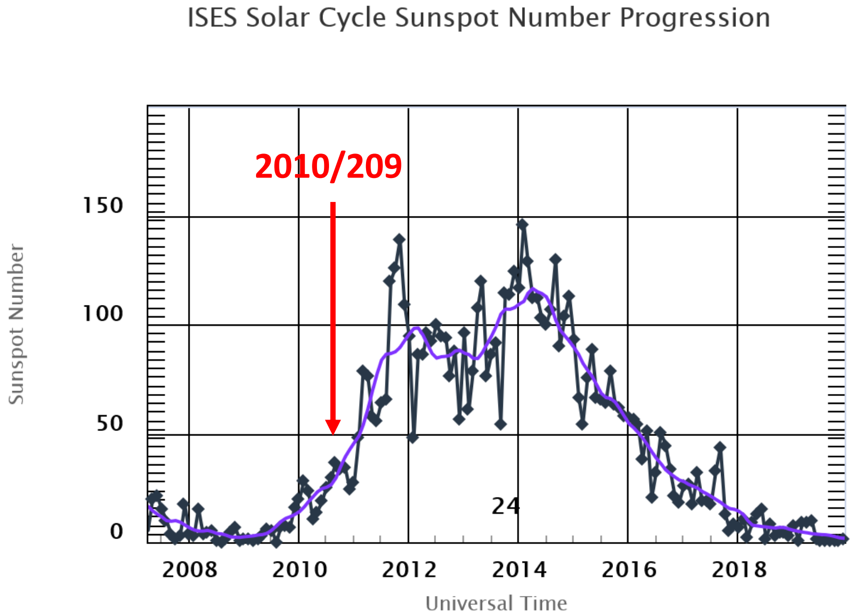


Simulated 2010 “Slow” and 2014 “Fast” Events

- “Slow” RCEs
  - Some variation in maximum negative charging but all events provide good sampling of RCE’s
  - Ne ~ $10^{10} – 10^{11}$ #/m^3







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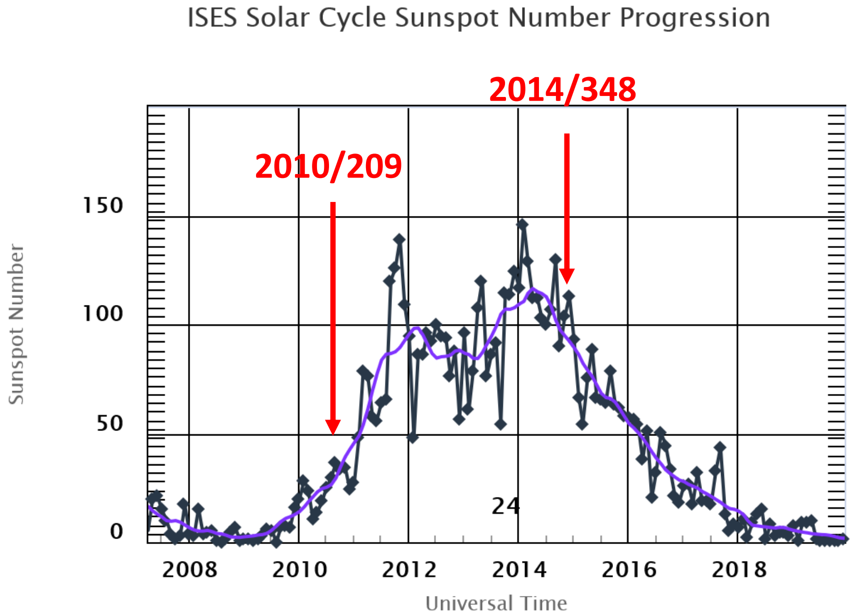
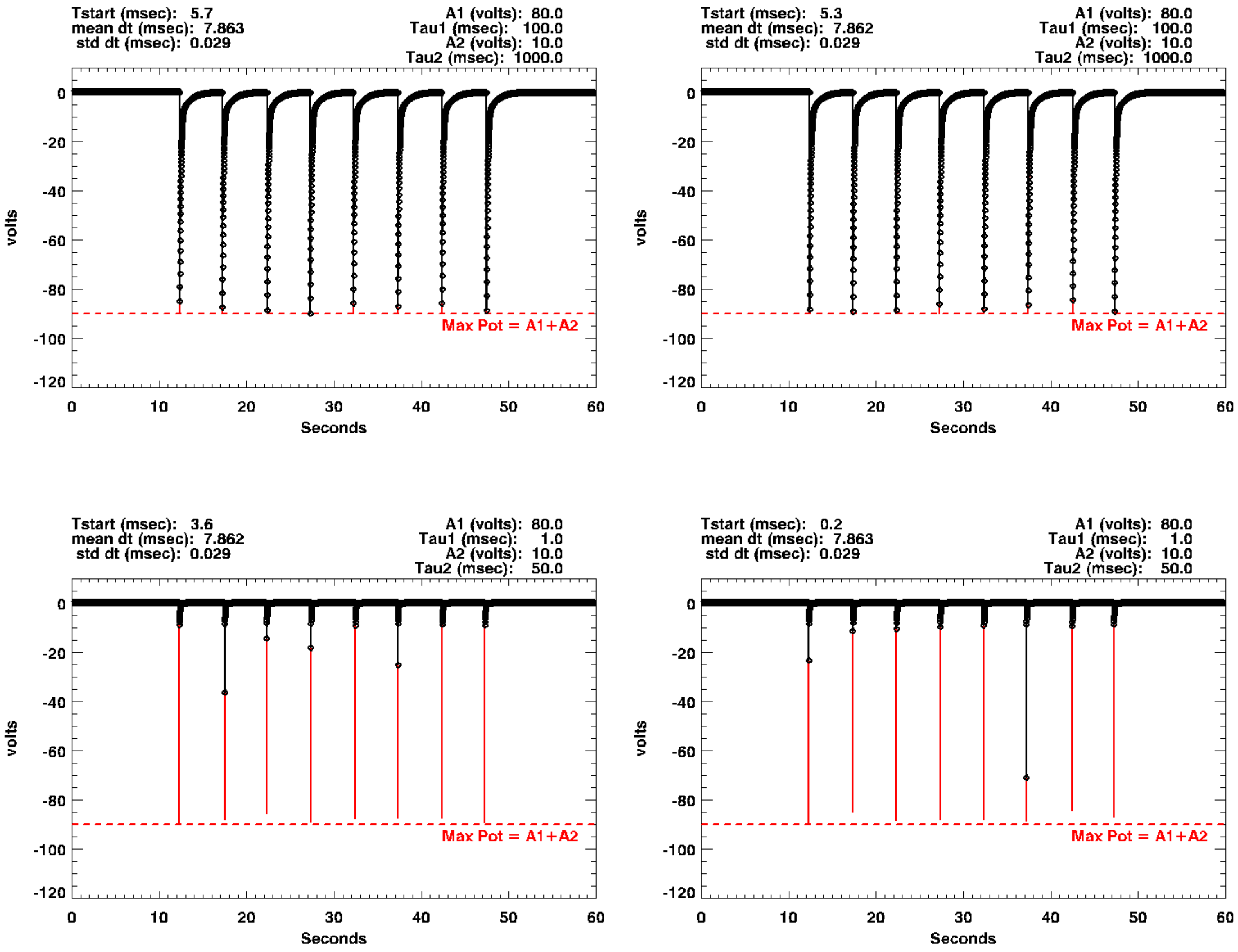
- “Slow” RCEs
  - Some variation in maximum negative charging but all events provide good sampling of RCE’s
  - Ne ~ $10^{10} – 10^{11}$ #/m^3
- “Fast” RCEs
  - Poorly sampled by FPP, wide range of peak values are due to under sampling
  - Ne ~ $10^{11} – 10^{12}$ #/m^3
- Simulations consistent with FPMU data!





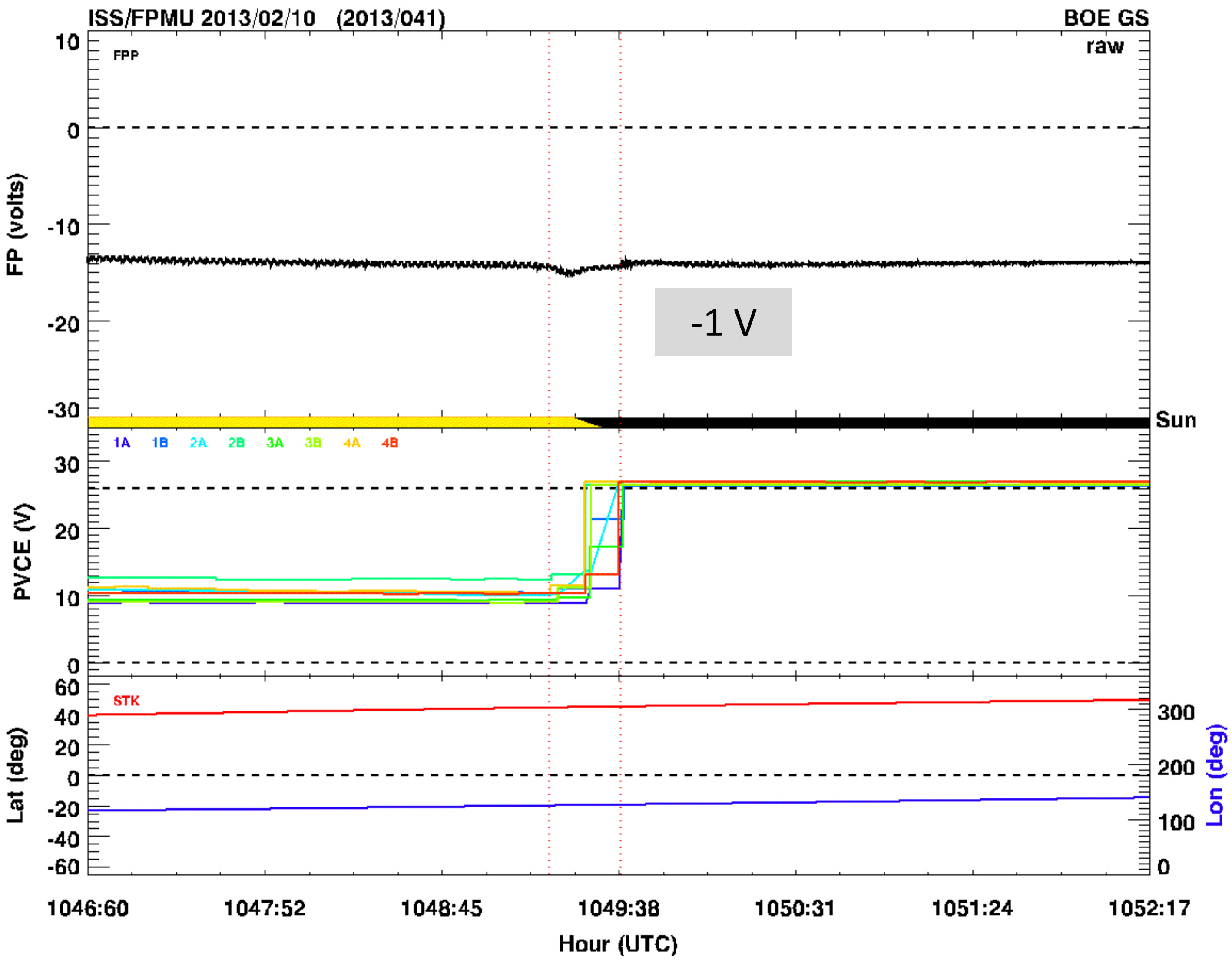
Eclipse Entry Charging

- Small charging peaks are frequently observed at eclipse entry

- Physics is similar to the sunlight unshunt events in full daylight

- PVAs typically mostly shunted near end of the day due to positive power margin, no need to charge batteries
  - Photovoltaic Control Electronics (PVCE) voltage proportional to number of shunted strings on an array
  - 26 V: all strings unshunted and PVA collecting full photocurrent
  - <26 V: multiple strings shunted with reduced photocurrent collection

- Arrays fully unshunted in sunlight before eclipse entry in preparation for next orbit
  - PVA RCE charging occurs following unshunt
  - Charging ends after ISS enters eclipse



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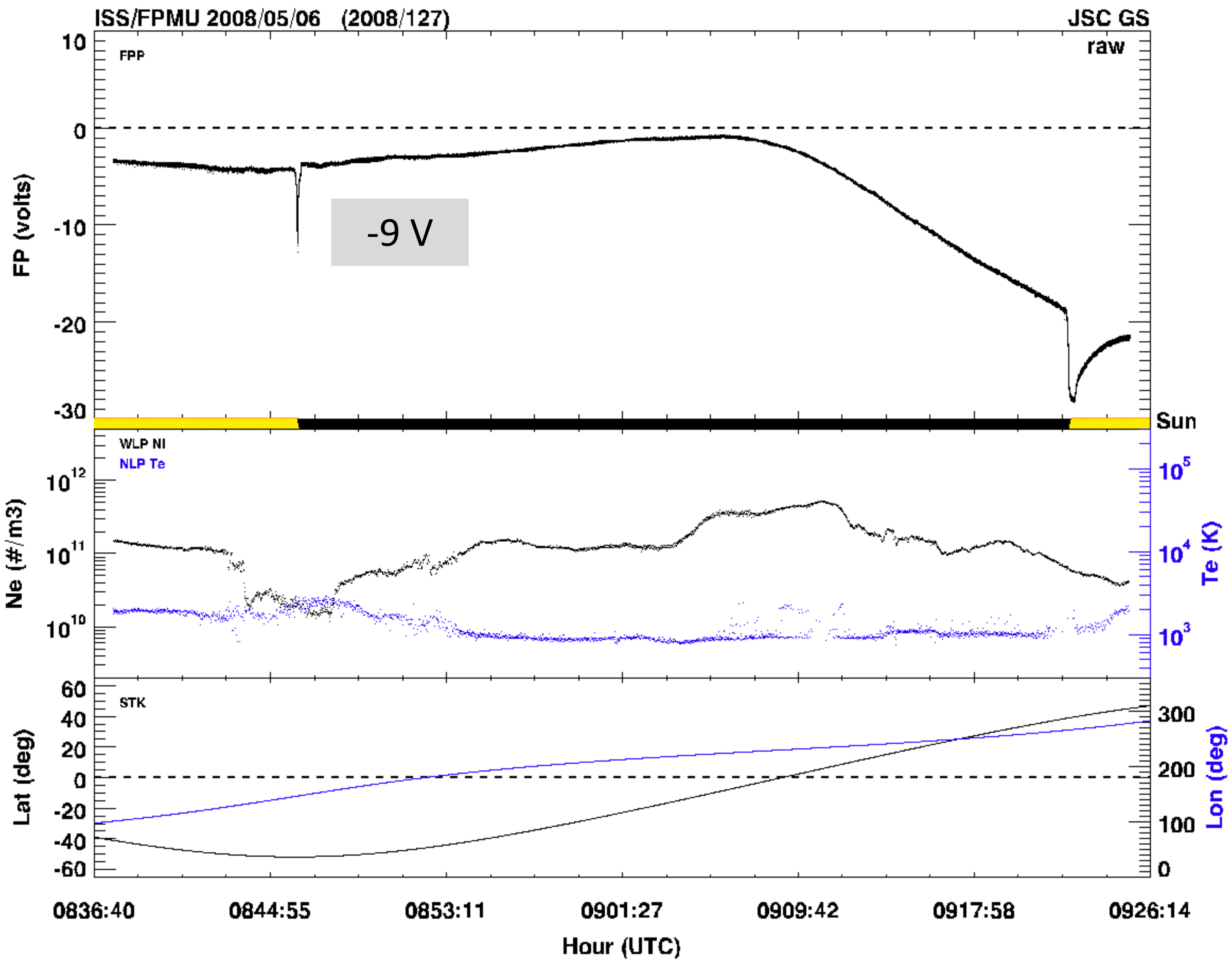

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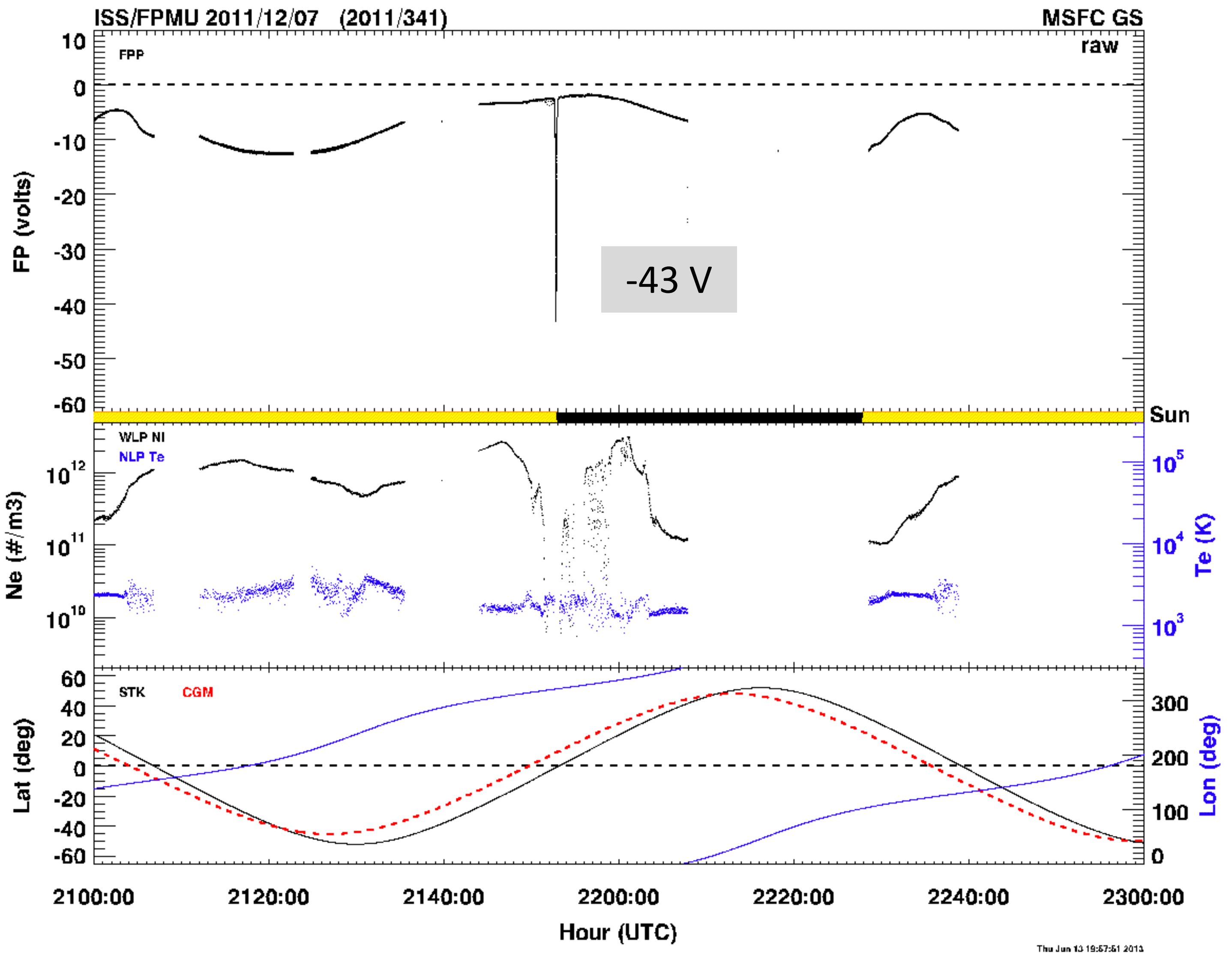


FPMU Replacement

- Original FPMU flight unit operated 14 years from August 2006 until 2020 (although designed for a 3-year life). Operations ended with a failed TVCIC power supply unit utilized by the FPMU.
- ISS Program replaced failed unit with flight spare during an EVA in September 2021
- New unit checked out successfully and is operational
- FPMU will continue to provide ISS charging and plasma environment data to meet ISS Program engineering needs and provide F2-region ionosphere data for science community

Surface of original probe

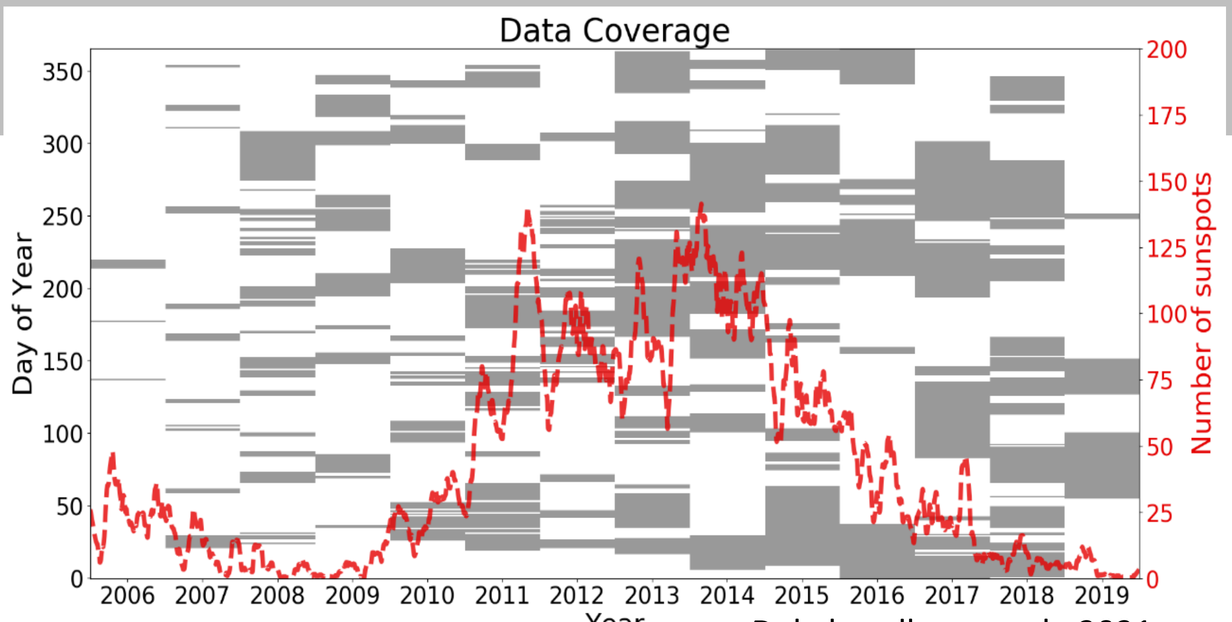
Image: T. Pesquet

Image: NASA

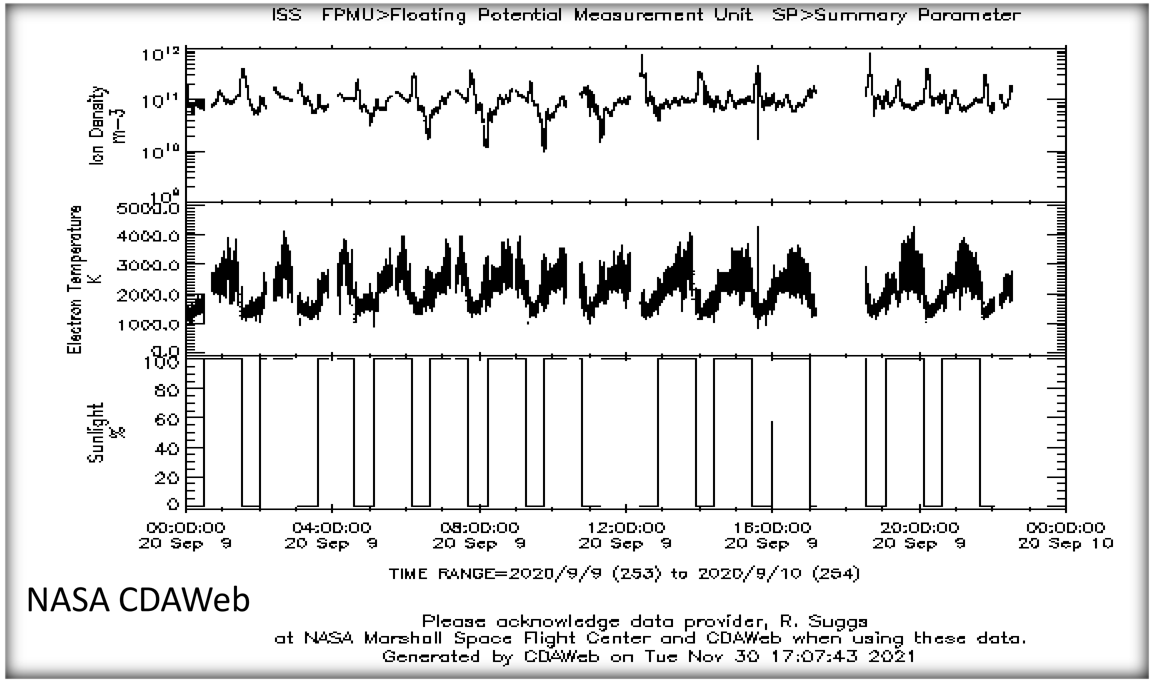
Image sources:
https://twitter.com/lalandechasles/status/1447913178533441542
https://forum.nasaspaceflight.com/index.php?topic=54588.140

CDAWeb Data Archives

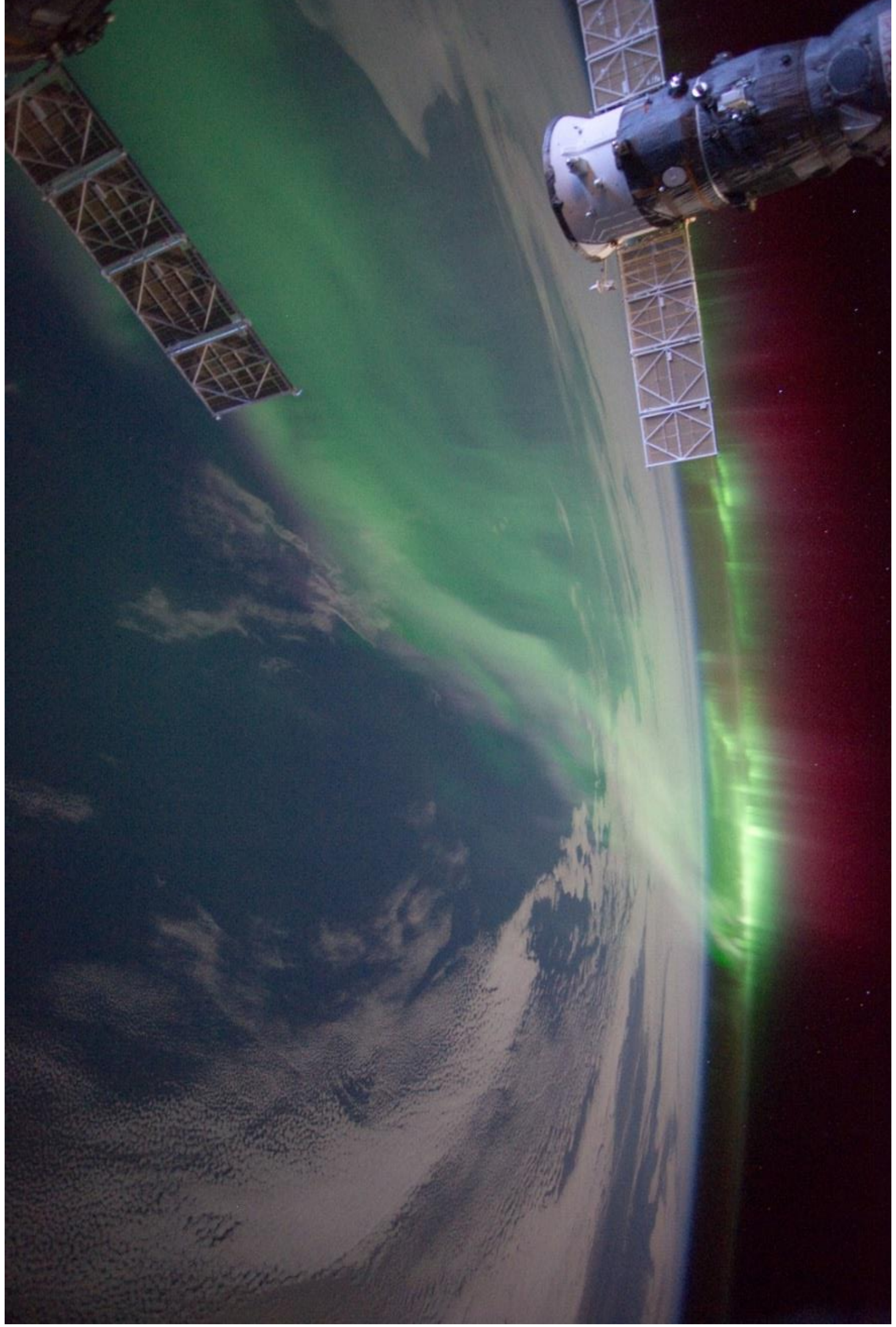
- FPMU data is available to the science community through the CDAWeb archive at GSFC's Space Physics Data Facility
  - URL: https://cdaweb.gsfc.nasa.gov/index.html/
  - Source: ISS   Instrument Type: Plasma and Solar Wind
  - Select: ISS_SP_FPMU
- Current CDAWeb FPMU holdings include the 2006/08/03 to 2020/09/14 (~full data set from original FPMU)
  - Time, lat/lon/alt, Ni, Te, ISS pitch angle, % illumination, TCC
- ERAU and MSFC are working to reprocess all FPMU records using updated Langmuir Probe algorithms (in progress) and update the CDAWeb holdings with better quality records and additional new parameters
  - Time, lat/lon/alt, Ni, Te, ISS pitch angle, % illumination, TCC
  - Floating potential, n(O+)/Ni
- CDAWeb FPMU holdings will continue to be updated periodically as records from the new FPMU instrument become available



Debchoudhury et al., 2021



NASA CDAWeb



Questions?

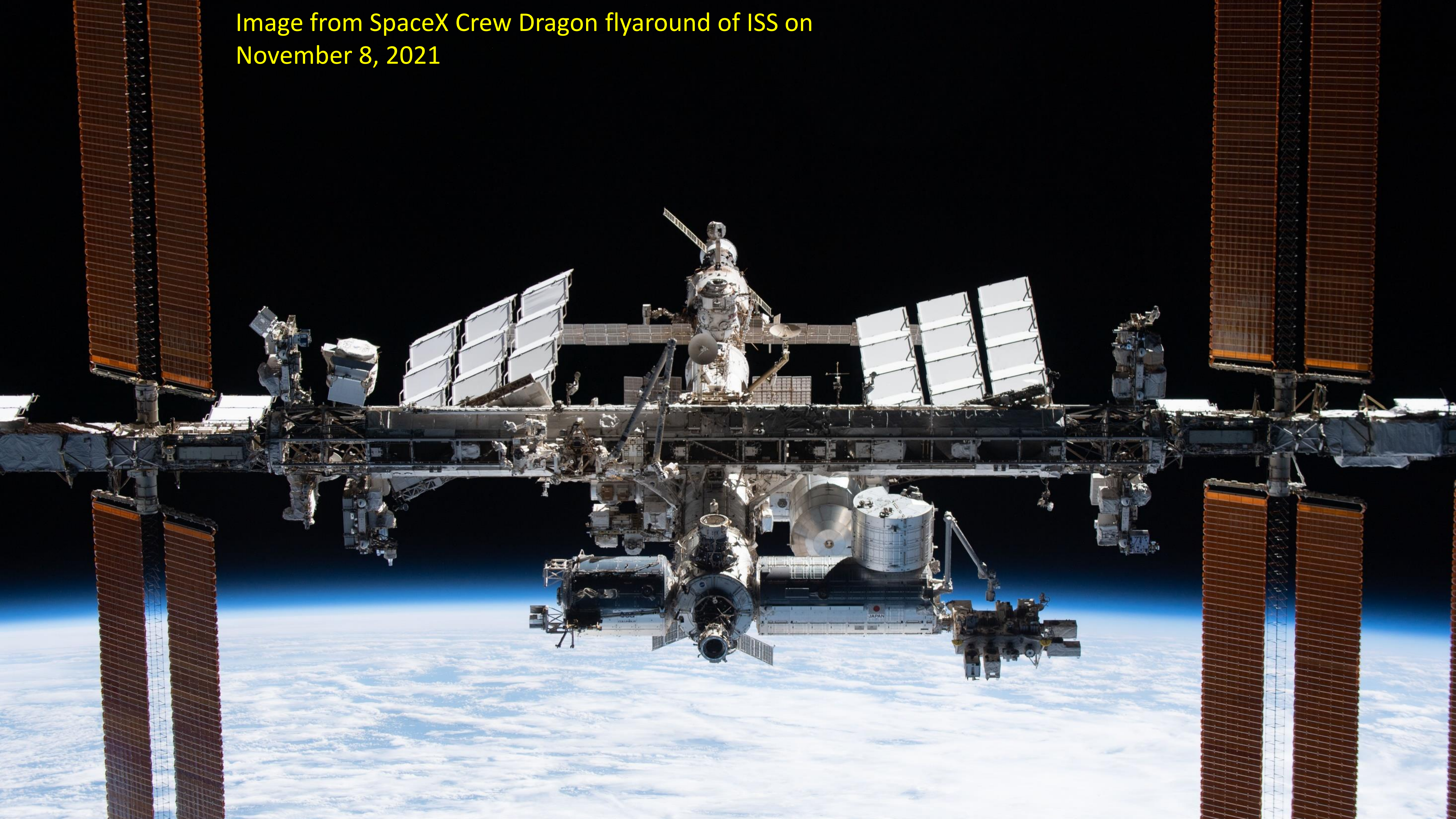
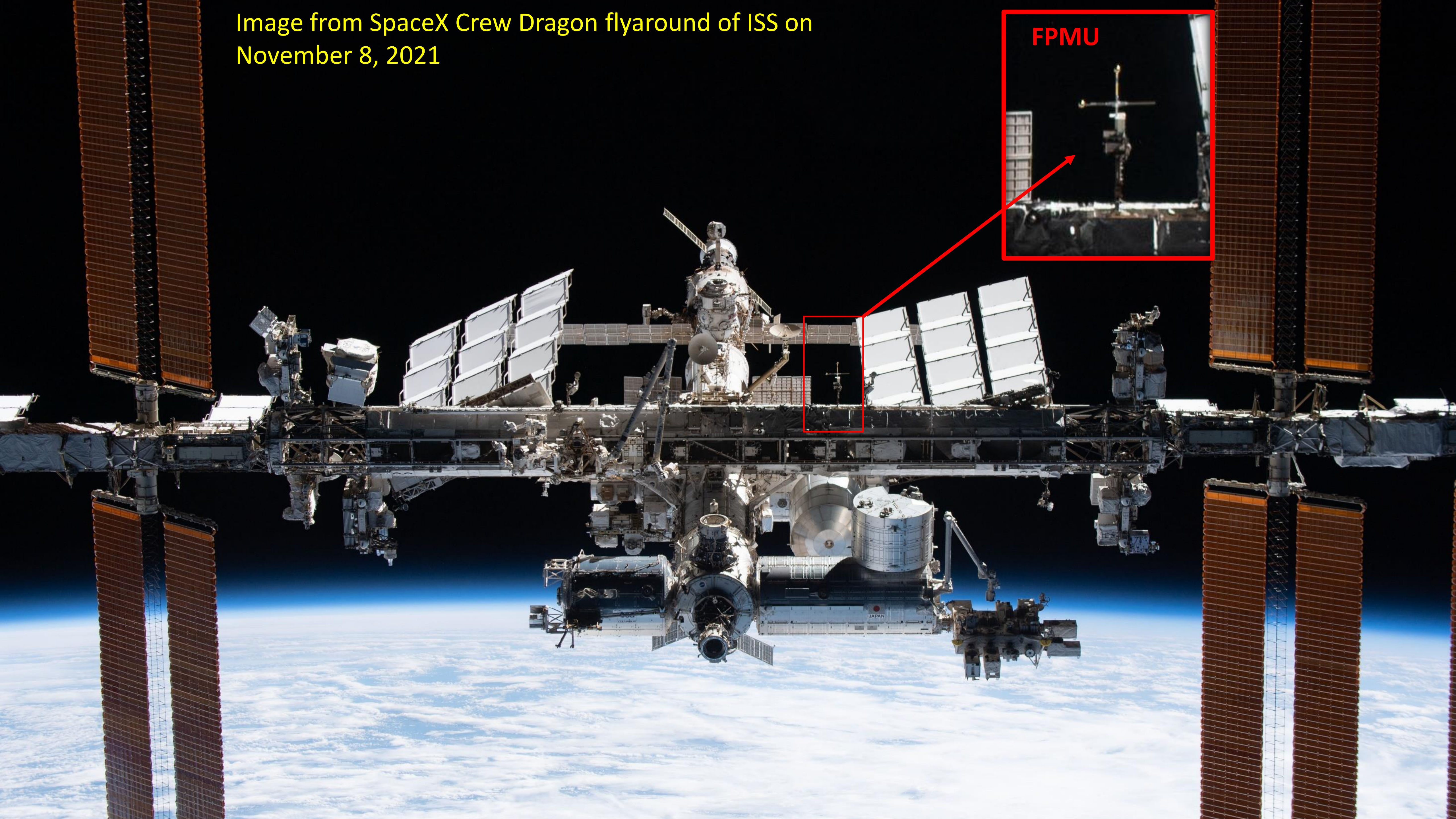


Image from SpaceX Crew Dragon flyaround of ISS on November 8, 2021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